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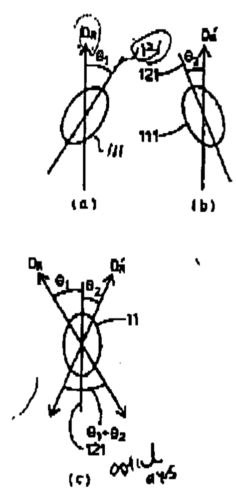
[54] [Title of Invention]

Liquid crystal electro-optical device

[57] [Summary]

[Purpose] To enhance the contrast ratio and to raise the display quality of an antiferroelectric liquid crystal device that exhibits switching among three states.

[Structure] The rubbing direction in the smectic A phase on the high-temperature side of an antiferroelectric phase and the rubbing directions on the upper and lower substrates as a function of the angle formed by the major axis (optical axis) of the liquid crystal molecules are determined, and high uniaxial orientation is attained. The contrast ratio is improved during multiplexing drive since the effects of the phase precursor phenomenon can be minimized by the anchoring force from two interfaces.



[Scope of Patent Claim]

[Claim 1] A liquid crystal electro-optical device having a structure in which liquid crystals with a phase series comprising, from the high-temperature side, an isotropic phase - smectic A phase - ferroelectric smectic phase - antiferroelectric smectic phase or an isotropic phase - smectic A phase - antiferroelectric smectic phase that are subjected to alignment processing on an electrode are sandwiched between substrates, wherein aforementioned orientation processing is carried out via rubbing processing on the alignment film formed on the substrate surface, said device characterized by the fact that the angle formed by the rubbing direction performed on the upper substrate and the rubbing direction performed on the lower substrate is the sum of the angles formed in the layer normal-line direction or in the direction of the major axis of the liquid crystal molecules and the direction of rubbing processing at the interface of each substrate in the thermal region of the smectic A phase.

[Detailed Description of the Invention]

[0001]

[Field of Industrial Utilization] The present invention concerns an electro-optical device such as a display or light valve, specifically, a display that uses liquid crystal material.

[0002]

[Related Art] Research has been actively carried out on switching among three states of ferroelectric liquid crystals as one means of eliminating the fundamental problems associated with conventional surface-stabilized ferroelectric liquid crystals (SSFLC). (Consult A.D.L. Chandani et al.: Jpn. J. Appl. Phys., 27, L729 (1988), A.D.L. Chandani et al.: Jpn. J. Appl. Phys., 28, L1265 (1988).) The main features of switching among three states are

(1) Antiferroelectric-ferroelectric phase transition due to voltage application has a steep threshold characteristic with respect to direct-current voltage. (Figure 3).

[0003] (2) Antiferroelectric-ferroelectric phase transition is accompanied by a wide optical hysteresis, and the selected state can be maintained as long as a bias voltage is applied after an antiferroelectric phase or a ferroelectric phase is selected (Figure 3).

[0004] (3) The two orientation states in an electric field-induced ferroelectric phase can be made optically equivalent.

[0005] (4) Since polarization of the electric charge in a liquid crystal substance can be prevented, there is no deterioration over time of the electro-optical characteristics such as is seen in SSFLC.

[0006] The display principles are explained using Figure 2. Optical axis OA in the antiferroelectric phase is perpendicular to the smectic layer. As shown in Figure 2 (b), when a cell comprising liquid crystal 6 sandwiched between two glass substrates 1, 2 on which transparent electrodes 4, 5 and liquid-crystal alignment films 9, 10 are formed is disposed between two polarizers 11, 12 whose polarization axes are perpendicular to each other such that optical axis OA is parallel to one of the polarization axes, the element goes to a light-blocking condition (tentatively OFF). Even if the voltage waveform whose absolute value is $|V(A\text{-}F)t|$ (see Figure 3) is applied on this condition, the light transmittance changes very little and the OFF condition can be maintained. Conversely, if the absolute value of the applied voltage waveform is $|V(A\text{-}F)s|$ or more, the liquid crystal will respond and change to ferroelectric phase (+) or ferroelectric phase (-) having optical axes OF (+) and OF (-), spontaneous polarization Ps (+) and Ps (-). Since the optical axes form angle θ (+) or θ (-) with the polarization axis, a light transmission condition (tentatively ON) is set. Since angles θ (+) and θ (-) are equal, they can both be treated as being optically equivalent. In a conventional device, a polyimide liquid crystal orientation film is rubbed on one side of a substrate to control the direction of the optical axis OA in the antiferroelectric phase.

[0007]

[Problems Solved by the Invention] However, conventional device have the following two defects.

[0008] One concerns the uniformity of the alignment of the liquid crystal molecules. During phase transition from high temperatures, the major axis of the smectic A phase liquid crystal molecule frequently grows at an angle to the rubbing direction of the alignment film interface, but when liquid crystal material having such properties is injected in a cell subjected to rubbing in a direction parallel to or antiparallel to the bilateral interfaces, two types of domains are formed because of the individual interfaces, and the layer direction is maintained in the smectic phase as well on the low temperature side. As a result, two different optical axes coexist in the plane in the antiferroelectric phase, and the contrast ratio falls markedly during operation. This phenomenon can be avoided by rubbing the interface on one side only, but the uniaxial properties of the molecular alignment fall because the anchoring force from the interface weakens.

[0009] Another defect is the undesirable phenomenon termed the phase transition precursor phenomenon that occurs during switching between the antiferroelectric phase and the ferroelectric phase due to the electric field. As seen in

Figure 3, this is observed as a continuous increase in the amount of light transmittance in regions where the applied voltage is below the threshold value. Consequently, this is a major cause of the decline in the contrast ratio in multiplexing driving. This phenomenon could be inhibited by high-density rubbing at the bilateral interfaces since it is dependent on the interface anchoring force, but the aforementioned first defect makes that too difficult.

[0010] The present invention was devised to solve aforementioned problems. The purpose is to provide a liquid crystal electro-optical device that adequately makes use of the features of switching among three states.

[0011]

[Means of Solving the Problems]

To solve aforementioned problems, the liquid crystal electro-optical device pursuant to the present invention has a structure in which liquid crystals with a phase series comprising, from the high-temperature side, an isotropic phase - smectic A phase - ferroelectric smectic phase - antiferroelectric smectic phase or an isotropic phase - smectic A phase - antiferroelectric smectic phase that are subjected to orientation processing on an electrode are sandwiched between substrates, wherein aforementioned orientation processing is carried out via rubbing processing on the alignment film formed on the substrate surface, said device characterized by the fact that the angle formed by the rubbing direction performed on the upper substrate and the rubbing direction performed on the lower substrate is the sum of the angles formed in the layer normal-line direction or in the direction of the major axis of the liquid crystal molecules and the direction of rubbing processing at the interface of each substrate in the thermal region of the smectic A phase.

[0012]

[Embodiments] The present invention is explained in detail below with reference to embodiments. The sample used was fabricated by forming a polyimide orientation film on transparent electrodes and injecting the liquid crystal material 4-(1-methylheptyloxycarbonyl)phenyl 4'-octyloxybiphenyl-4-carboxylate (MHPOBC) in a cell with a 1.7-μm gap by heating, and the ambient temperature was maintained in the temperature range of the antiferroelectric chiral smectic C phase (S_{CA}^* phase). The structure of the element is shown in Figure 2 (b).

[0013] (Embodiment 1) Figure 1 is a general view of an embodiment of the present invention. In the figure, DR and DR' represent the rubbing directions of the upper substrate and the lower substrate, 111 represents the liquid crystal molecule and 121 represents the major axis or the optical axis of the liquid crystal molecule. (a) and (b) represent the inclinations of the major axis of the liquid crystal molecule from the rubbing direction as an effect of the upper substrate and the lower substrate. The angles θ_1 and θ_2 can be determined by holding the cell subjected to rubbing on only one side of the substrate in the smectic A phase and observing it under polarizing microscope. In aforementioned sample, $\theta_1 = \theta_2 = 3.4^0$. The device having the structure of Figure 1 (c) was fabricated based on this information. Isotropic phase liquid crystal was injected in a cell in which the upper substrate and lower substrate were rubbed so that $\theta_1 + \theta_2 = 6.8^0$. It was then cooled at 3.0^0C/min, and upon transition to smectic A phase, a uniaxial orientation state was obtained having a distinct extinction phase under crossed Nichol prism. Furthermore, upon cooling to the S_{CA}^* phase temperature, the layer normal-line direction in the antiferroelectric phase without imposition of an electric field and the polarization axis coincided, which permits a uniform acoustic state to be reached. The temperature of the device was held at 90^0C, and multiplexing driving which was attempted resulted in a contrast ratio of 1:42.

[0014]

[Effects of Invention] As explained above, the contrast ratio of a device can be drastically raised by improving the molecular alignment of antiferroelectric liquid crystal devices that exhibit tristable switching behavior pursuant to the present invention. The present invention can be applied to superfine liquid crystal display devices and light valves, spatial light modulators, etc.

[Brief Description of Drawings]

[Figure 1] A diagram presenting the structure of an embodiment of the present invention.

[Figure 2] A general view of the device used in an embodiment of the present invention.

[Figure 3] A diagram explaining the electro-optical characteristics of a device used in an embodiment of the present invention.

[Explanation of the symbols]

DR, DR' Rubbing direction

111 liquid crystal device

121 direction of the major axis of a liquid crystal molecule (optical axis)

OA optical axis in the antiferroelectric phase

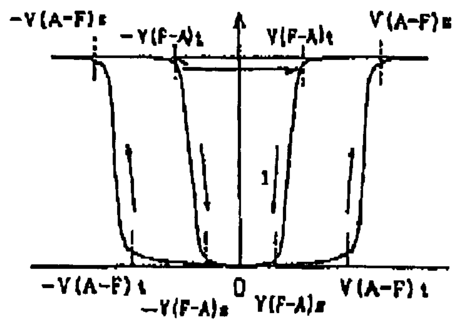
OF (+) alignment direction of molecule in ferroelectric phase (+) (optical axis)

OF (-) alignment direction of molecule in ferroelectric phase (-) (optical axis)

1, 2 glass substrates
3 spacer
4, 5 transparent electrodes
6 liquid crystal layer
9, 10 liquid-crystal alignment films
11, 12 polarizers

Figure 3

Light transmittance



Applied voltage

Figure 1

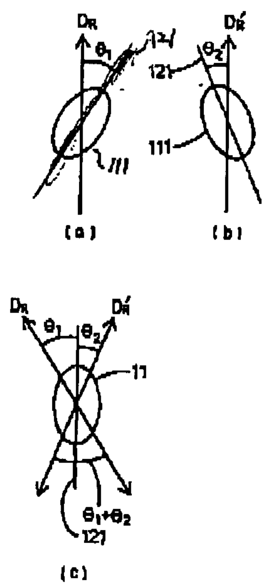
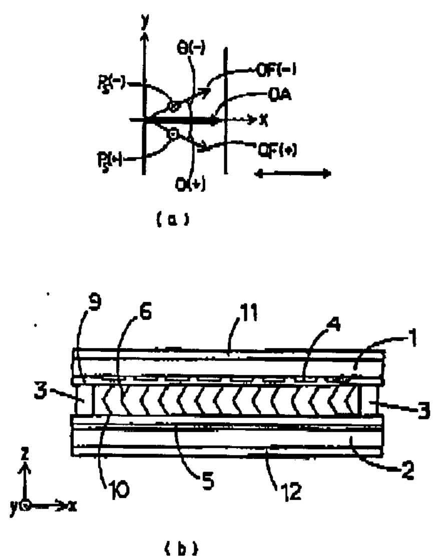


Figure 2



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